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HYDRAULIC SCALED MODEL TESTS FOR THE OPTIMIZATION OF APPROACH CHANNEL EXCAVATION AND APPROACH FLOW CONDITIONS OF HARAZ MORNING GLORY SPILLWAY

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ABSTRACT

Haraz dam under construction is located along Tehran-Amol road, 20 km upstream of the Amol city. A tunnel has been designed to detour the traffic temporarily around the dam site to avoid any closure of the main road. This tunnel will be integrated in the morning glory spillway of the dam.

According to the road design constraints and the tunnel layout, the morning glory entrance is located next to the dam abutment. This is the main challenge in Haraz spillway in comparison with conventional morning glory spillway approach channel.

A spillway hydraulic model was set up in Tehran Water Research Institute and the corresponding tests were performed on it subsequently. According to the test results and as expected, some disturbances in the stream lines were observed of the approach flow nearby the abutment which had some negative impacts on the spillway capacity and its performance.

Several alternatives were studied to optimize the hydraulic conditions using the hydraulic model. Finally, taking advantage of piers in a specific position on the ogee crest was found to be the most promising solution for reducing flow disturbances. This method could be an innovative solution for morning glory spillways, which have to be located close to the abutments.

1. PREAMBLE

Haraz Earthfill Dam with mixed core and height of 150 m is being constructed in 20 km upstream of the city of Amol. This dam would supply the water right of over 100 000 ha of paddies of Haraz Plain which are now being irrigated by the water released from Lar Dam. Allowing for the increasing trend of the drinking water demand from Tehran, Lar Dam would no longer feed Haraz Plain in future. Haraz Dam would also supply the drinking water of the populated cities of Mazandaran Provinces. Generation of electricity and regulation and conveyance of surplus water to the east of Mazandaran and Golestan Provinces are considered as other objectives of this project.

The dam site is located alongside Amol-Tehran (Haraz) Road which is one of the main and heavy-traffic northern roads of Iran. In view of the fact that about 11 km of the existing road will be submerged after impounding, a replacement road is under construction away from the reservoir. In the interim, to avoid blocking the road by the dam embankment during dam construction, a 720 m long and 9.7 m diameter tunnel has been constructed to be resorted to as a temporary diversion during the construction. It will subsequently serve as a tailrace tunnel of a morning glory spillway connected with a 70 m high vertical shaft (Figure 1).

Since the tunnel is going to function as both road diversion and spillway tailrace tunnel, it would be necessary to observe the standards of road and spillway all together. This paper describes first the considered standards before discussing the optimization of the spillway making use of the hydraulic model studies.

Figure 1. Dam construction, Temporary Diversion Tunnel inlet and Haraz Road

At present, the tunnel is being used for transportation purposes and the dam body construction activities are in progress in that portion of Haraz Road which is not used any more (Figure 2).

Figure 2. Internal Section of Diversion Tunnel (Left); Transportation of Vehicles (Right)

2. SELECTION OF SPILLWAY TYPE AND SITE PLAN

The study results depicted that the morning glory spillway tailrace tunnel can temporarily be served as road diversion tunnel in the course of the dam construction. Allowing for the topographic conditions and observing the required standard radius of the route, the tunnel length was determined 720 m and its internal diameter was chosen by to 9.7 m commensurate with the design standards of the temporary road tunnels for two lanes. The tunnel section is horseshoe and its dimensions were checked for the maximum releasing capacity of the spillway during PMF.

The following criteria were observed for the alignment of the tunnel and selecting the location of the spillway inlet structure:

- Topographic conditions and preventing from high volume of excavation for the inlet channel
- The necessity of connecting the inlet and outlet of the spillway tunnel to the present road
- Observing the road standards (comprising the curve radius, tunnel dimensions, slope, etc.)
- Observing the hydraulic standards of spillway (tunnel diameter, tunnel outlet proportionate to the river, the necessity of having a straight tunnel after the shaft, etc.)

Taking into consideration the aforementioned criteria, the tunnel route was designed with a 250 m radius curvature and central angle of 30 degrees. The tunnel inlet and outlet were connected to the road subsequently.

The layout of the dam and the temporary diversion tunnel (spillway tunnel) and the longitudinal profile of the tunnel are shown in Figures 3 and 4 respectively.

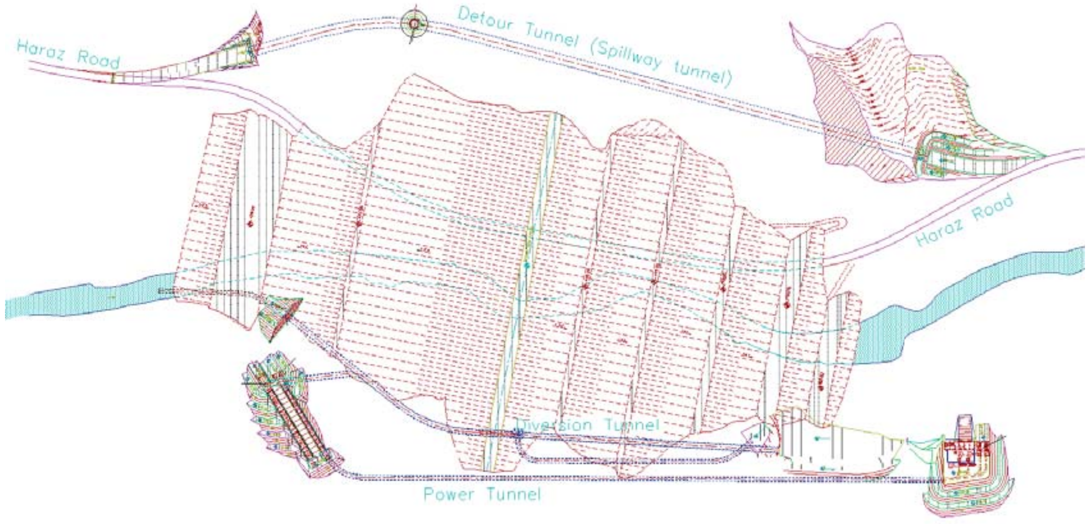

Figure 3. Layout of Dam Body, Tunnels and Haraz Road

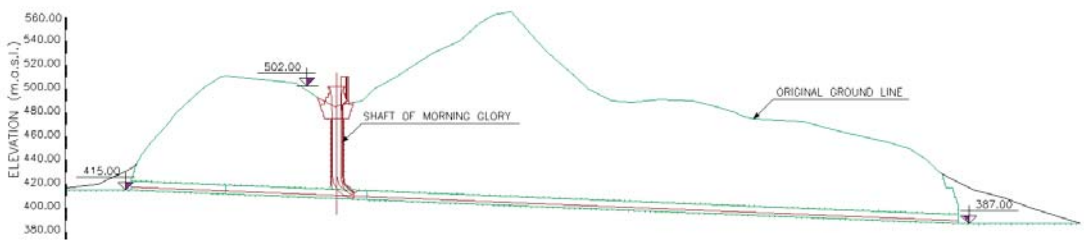

Figure 4. Longitudinal Profile of Spillway and Haraz Road Tunnel

3. SPECIFICATIONS OF FLOOD RELEASE SYSTEM

The morning glory spillway consists of and approach channel, morning glory structure, vertical shaft, aeration shaft, elbow, tailrace tunnel followed by flip bucket. The topographic location of the spillway is shown in Figure 55.

The selection of design flood and safety check flood has been performed based on the classification of the dam and downstream losses. According to the height and reservoir capacity of Haraz dam, it is classified as a large dam. Thus the design flood should be equal to a flood with a recurrence interval of 1/10000, whereas the safety check flood should correspond to PMF.

3.1 Morning Glory Structure

The external diameter and length of the inlet sill of the spillway are 35.8 m and 106.5 m respectively. The spillway crest level is at 502 masl (normal reservoir operation water level in meters above sea level).

As seen in Figure 4, the location of the morning glory inlet structure into the existing waterway/road tunnel is about 163 m away from the spillway inlet. This limits the excavation volumes of the inlet channel and the structure can be located at the end of the tunnel curvature. Accordingly, the tunnel alignment is straight from the vertical shaft to the end. In spite of observing the above criteria, the inlet structure (circular ogee) is not far enough from the rock abutment. Consequently this is the only difference between the design of the approach channel of this morning glory and the standard recommended for the approach channel of other morning glory spillways.

Figure 5. Temporary Diversion Tunnel Inlet, Vertical Shaft and Spillway Inlet Structure

3.2 Vertical Shaft

The internal diameter of the vertical shaft is 8.3 m. It has been located 163.6 m away from the tunnel inlet portal. The total shaft length is 61 m which is connected to a vertical elbow at the end.

3.3 Aeration Shaft

An aeration shaft with an internal diameter of 2 m has been foreseen to supply enough air to ensure the free surface flow inside the tailrace tunnel. The aeration shaft is connected to the tunnel immediately after the control section. The aeration shaft has a length of about 105 m.

3.4 Tunnel

The total tunnel length from the shaft up to the outlet portal is 560 m. The tunnel section is a standard horseshoe profile with a diameter of 7.5 m. The longitudinal slope of the spillway tunnel is 3.9%.

3.5 Concrete Channel and Flip Bucket

A flip bucket has been considered at the end of the tunnel to direct the spillway outflow into the river. The total length of the flip bucket with a radius of 20 m is 13.5 m. The flip bucket lip has an angle is 30 degrees and is located at elevation of 388 masl.

4. SPILLWAY INLET STRUCTURE ALTERNATIVES

Due to before mentioned constraints, the morning glory inlet structure is too close to the abutment and its adjacent topography. It was therefore not possible to design and construct the inlet channel based on the standard parabolic equation of the morning glory spillways (Hager & Schleiss, 2009) which would have resulted in a considerable excavation volume. Accordingly, the following alternatives were taken into consideration in design phase for Haraz Dam Spillway:

4.1 Alternative 1: Semi-morning Glory Spillway

In this alternative, the part located adjacent to the abutment is closed by a wall and the water flows into the shaft only through the reservoir part (Figure 6- Left). In this case, the topography behind the spillway does not affect the water flowing into the morning glory spillway. Nevertheless, the omission of approximately half of the morning glory sill would result in a significant reduction of the spillway discharge capacity.

4.2 Alternative 2: Full-shape Morning Glory Spillway and Omission of the Standard Parabolic Equation

In this alternative, the morning glory geometry is not going to be changed. Nevertheless the standard parabolic equation for the inlet channel was abandoned in order to prevent from substantial excavation volumes. The above excavation considerably affects the project economy, increases the construction difficulties and makes the abutment instable as a result of the creation of high trenches. Figure 6 – Right indicates the plan view of the morning glory spillway.

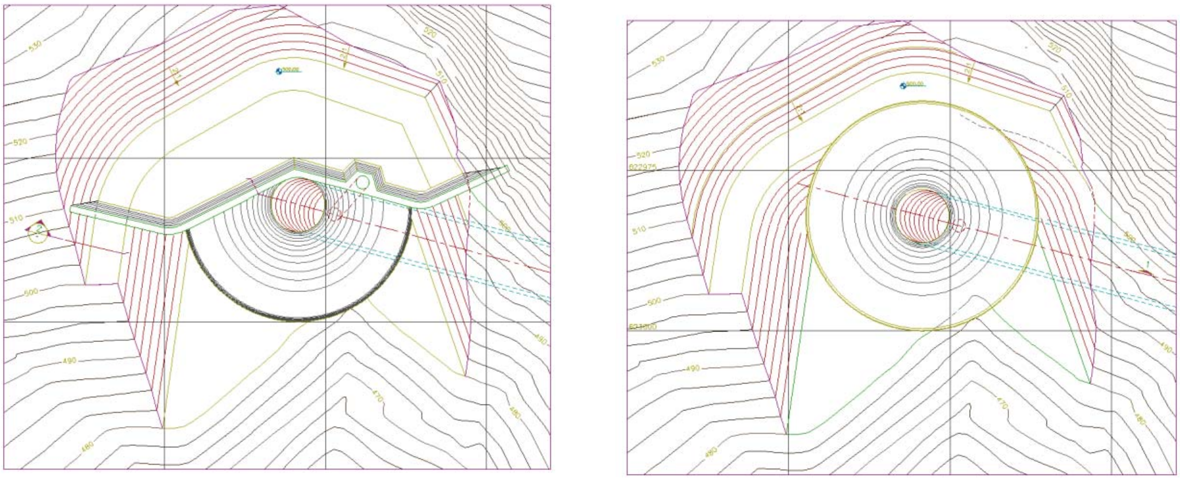

Figure 6. Semi-morning glory spillway (Left); Full-shape morning glory spillway (Right)

5. HYDRAULIC MODEL

The hydraulic model of the spillway with a scale of 1/ 30 was built at the Water Research Centre of Tehran. The corresponding tests were performed in order to study the hydraulic conditions and select the most appropriate alternative for the spillway.

5.1 General Specifications of Hydraulic Model

The hydraulic model includes three following parts (Figure 8):

a. Tank: It comprises an area of the reservoir area adjacent to the spillway with dimensions of 4 x 6 x 1.3 m (L x W x H) constructed on a steel frame with a height of 4 m (Figure 7)

b. The tank was made of steel and the reservoir topography was reconstructed inside the tank according the maps. The model required discharge was supplied by two pumps. In order to avoid turbulence in the incoming flow, the flow was lowered below the topography level; then, it was raised slowly to the spillway area (Figure 8).

c. Morning glory spillway: It includes inlet channel, morning glory, vertical shaft, transition, aeration conduit, horizontal tailrace tunnel and flip bucket

d. Tailrace Tank: It comprises the tailrace area of the flip bucket and few meters of the river at downstream.

The hydraulic model was constructed from el. 350 masl (bottom level of the main hall of the laboratory) up to el. 510 masl (2 m above the dam crest level). The model height was totally 5.3 m and its length was 6 m allowing representing the tunnel and its up and downstream tanks.

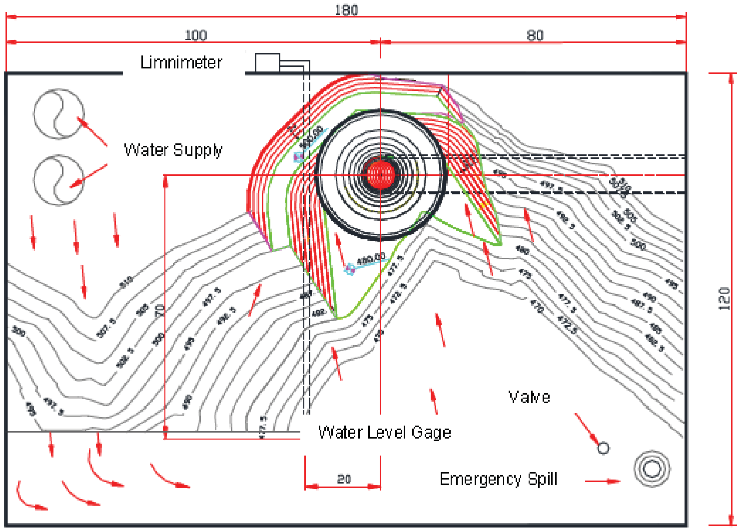

Figure 7. Plan of upstream tank of the model (in cm of physical model)

The following figures indicate different parts of the spillway hydraulic model.

Figure 8. Photos from different parts of the spillway physical model

5.2 Test Description

The tests were initially conducted on the full-shape morning glory spillway. According to the test results and as expected, some disturbances in the stream lines were observed of the approach flow nearby the abutment which had some negative impacts on the spillway capacity and its performance with return periods of more than 1000 years (Figure 9).

Figure 9. Disturbed flow adjacent to the abutment (PMF = 1000 m^3/s)

5.2.1 Alternative 1 (Semi-morning Glory Spillway)

As noted above, in this alternative, the part located adjacent to the abutment is restricted by the topography and the water flows into the shaft only from the reservoir side. The following figure depicts the tests results for PMF conditions. As observed, the flow disturbance is moved to the walls' sides, which considerably affects the discharge capacity (Figure 10).

Figure 10. Use of a wall to close the spillway sill adjacent to the abutment

5.2.2 Alternative 2 (Use of full-shape morning glory spillway combined with flow directing piers)

In this alternative, the full shape of the morning glory spillway was used. In order to omit or decrease the flow disturbances and to improve the discharge capacity, some piers with different locations were used in order to direct to flow. Tests were conducted under different flow conditions. Figure 11 indicates the flow conditions without pier and with 2, 3 and 4 piers.

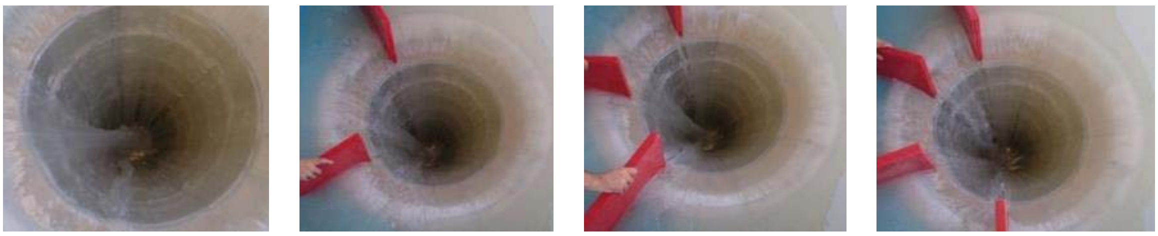

Figure 11. Flow conditions without and with 2, 3 and 4 flow directing piers (PMF)

As it can be seen in Figure 11, the flow disturbance decreased significantly in the alternative with 4 piers. Consequently, the location of the four piers was fixed for the rest of studies. Besides, in order to have a pleasing symmetry in the model, two piers were added to the other side of the model which had no effect on the flow based on the test results but which can avoid rotational flow around the spillway (Figure 12).

Figure 12. Final design of morning glory spillway

The discharge of the spillway was measured for two cases of with 6 and without piers and the results are shown in Figure 13.

The reservoir water level was measured at 4 m distance from the spillway (120 m in the real conditions)

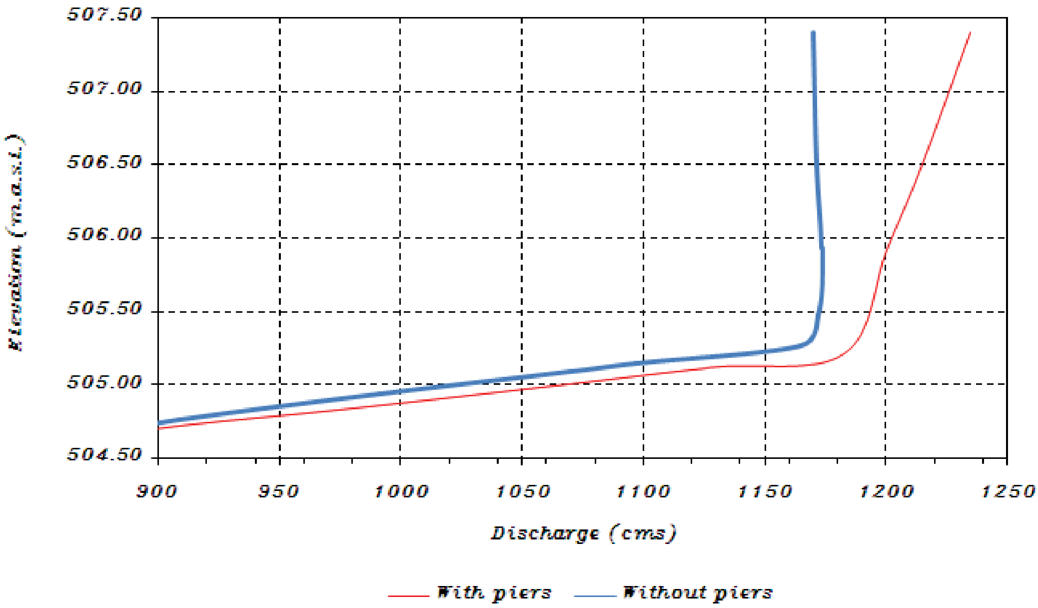

Figure 13. Spillway discharge rating curve for two cases of with 6 and without piers

According the test results there is no considerable difference between the discharge capacity of the two cases of with and without piers when the flow is still free in the shaft. Nevertheless, in case of higher flows into the vertical shaft, the piers significantly decrease the threshold at which the shaft becomes pressurized. These results in higher flood release safety.

The tests revealed that in the case of without piers, the vertical shaft started to be pressurized with a discharge of 971 m^3/s (Crotch Point). Nevertheless in the case of 6 piers, the vertical shaft becomes only pressurized for 1050 m^3/s.

6. CONCLUSION

Several alternatives were studied to optimize the hydraulic conditions of a morning glory spillway combined with a temporary high way tunnel using the hydraulic model.

The morning glory inlet structure had to be located close the reservoir abutment which resulted in significant flow disturbances and discharge capacity reduction. By directing the flow with 6 piers on the ogee, the flow disturbances could be eliminated. The hydraulic model tests helped to define the location, dimensions of the 6 piers were refined and determined in the model and it was realized that making use of the 6 middle piers.

This solution with flow directing piers could be applied for other morning glory spillways, which have to be located close to the reservoir abutments.

7. ACKNOWLEDGEMENTS

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